AI and Machine Learning for Treatment Planning and Image Segmentation

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Disclosures

- Varian Medical Systems
- NIH
- MD Anderson Cancer Center
- MD Anderson Internal Research Grant

Key Points

- Why automated contouring and treatment planning are essential in our quest to improve radiotherapy
- Brief overview of AI for medical imaging
- AI-based auto-segmentation
  - Normal tissues
  - Target volumes
- Automated treatment planning

Why Automated Treatment Planning

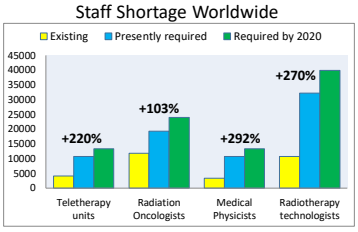


Figure from Kelly Kisling, PhD

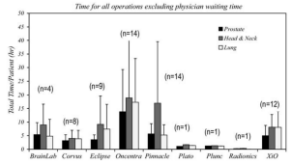
Data from Datta NR, Samiei M, Bodis S. Radiation Therapy Infrastructure and Human Resources in Low- and Middle-Income Countries: Present Status and Projections for 2020. IJROBP. 2014;89(3):448-57.

Why Automated Treatment Planning

- Time consuming task

  = $

- Involves a team of highly trained staff
  - Several hand-offs
- From simulation CT to plan approval ~ 5 work days



Indra J. Das, PhD, Vadim Moskvin, PhD, Peter A. Johnstone, MD. Analysis of Treatment Planning Time Among Systems and Planners for Intensity-Modulated Radiation Therapy! Am Coll Radiol 2009;6:514-517

Why Automated Treatment Planning

Humans are "humans"

- "We are quite bad at making complex unaided decisions"
  (P Slovic,, B Fischhoff, and, and S Lichtenstein Annual Review of Psychology 1977 28:1, 1-39)
- As humans (professionals) we use our intuition, training, and experience to identify the "best" solution

Why Automated Treatment Planning

Humans are "humans"

We are not "perfect"

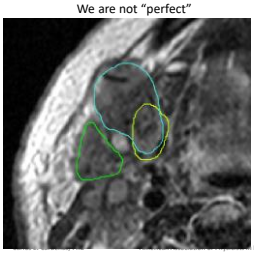
By Wren McDonald. https://newyorker.com

Different Interpretations/Ideas

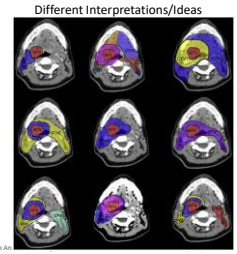
By Tom Fishburn. https://marketoonist.com

Why Automated Treatment Planning

We are not "perfect"



Different Interpretations/Ideas



Automation in Radiation Oncology

- Automation as Decision Support Systems
  - Not here to replace us, but to augment our knowledge
- Staff shortages
  - Low- and middle-income countries
- Reduce costs and improve clinical workflows
- Reduce uncertainties in radiotherapy

Introducing Artificial Intelligence

What is AI?

- Artificial intelligence is a subfield in computer science that focuses on the development of intelligent agents that mimic cognitive functions such as learning and problem solving.
- The goal of an artificial intelligence system is to perceive a problem and take an action that maximizes the likelihood of successfully achieving a desired goal.

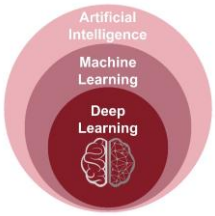


Figure 1. Illustration showing the relationship between artificial intelligence, machine learning, and deep learning.

Machine Learning

- Machine learning or statistical learning, is a subfield of artificial intelligence where mathematical algorithms are able to learn patterns from data which can then be used to make informed decisions when presented with new observations

Examples: LASSO, random forests, artificial neural networks, etc.

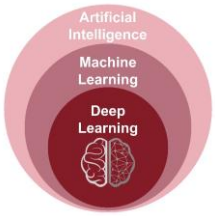


Figure 1. Illustration showing the relationship between artificial intelligence, machine learning, and deep learning.

Deep Learning

- Deep learning is a subfield of machine learning which focuses on the use of deep neural networks which were traditionally defined as artificial neural networks that have more than 2 "hidden" layers between the input and output layers; however, with today's computational power, deep neural networks can have hundreds of hidden layers.

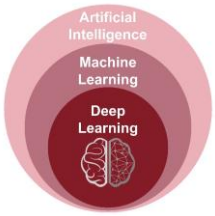
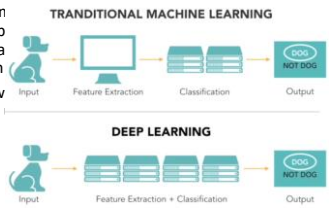


Figure 1. Illustration showing the relationship between artificial intelligence, machine learning, and deep learning.

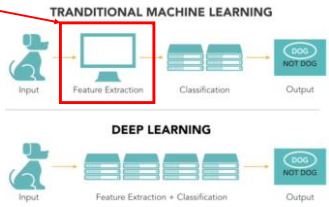
Machine Learning vs Deep Learning

- When con…aches, deep learning p…-defined features a…ning algorithm…el.
- This allow…n unseen data (not …



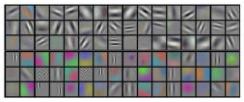
Machine Learning vs Deep Learning

Human Interaction



Convolutional Neural Networks

- Widely used in medical imaging analysis due to their ability to provide local connectivity between neurons of adjacent layers exploiting spatially local correlations.



Images from http://cs231n.github.io/convolutional-networks/

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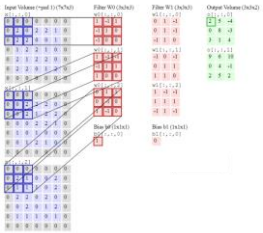
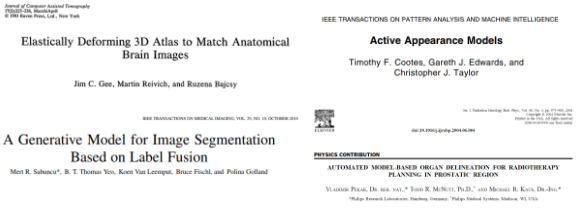


Images from http://cs231n.github.io/convolutional-networks/

AI-based auto-segmentation

A lot of history with non AI-based approaches



Elastically Deforming 3D Atlas to Match Anatomical Brain Images

Jim C. Gee, Martin Reivich, and Ruzena Bajcsy

A Generative Model for Image Segmentation Based on Label Fusion

Mert R. Sabuncu*, B. T. Thomas Yeo, Koen Van Leemput, Bruce Fischl, and Polina Golland

IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE

Active Appearance Models

Timothy F. Cootes, Gareth J. Edwards, and Christopher J. Taylor

PHYSICS CONTRIBUTION

AUTOMATED MODEL-BASED ORGAN DELINEATION FOR RADIOTHERAPY PLANNING IN PROSTATIC REGION

- Clinical deployment (2016) at MD Anderson of our in-house atlas-based auto-segmentation algorithm for head and neck normal tissues.

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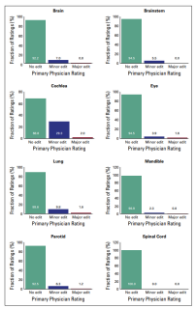
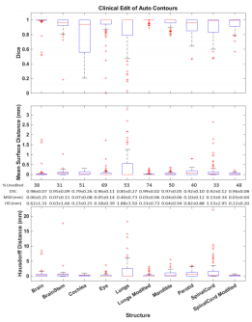
- Initial evaluation of the algorithm



McCarroll JGO 2018

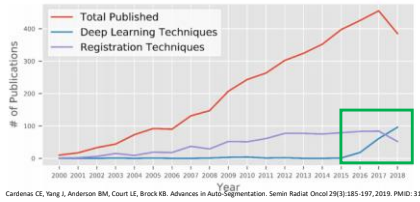
- Clinical deployment (2016) at MD Anderson of our in-house atlas-based auto-segmentation algorithm for head and neck normal tissues.
- Initial evaluation of the algorithm
- Retrospective analysis of 1st 128 consecutive cases treated using these contours and compared the clinical contours (edited if needed) and auto-segmentation
  - 50% of contours didn't require edits
  - Atlas-based clinically acceptable for the majority of cases

McCarroll JGO 2018



Deep Learning Boom

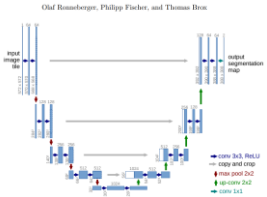
Medical image auto-segmentation publications in the past 2 decades



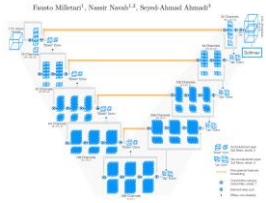
Cardenas CE, Yang J, Anderson BM, Court LE, Brock KB. Advances in Auto-Segmentation. Semin Radiat Oncol 29(3):185-197, 2019. PMID: 31027636.

U-net (2015) and V-net (2016)

U-Net: Convolutional Networks for Biomedical Image Segmentation



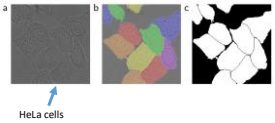
V-Net: Fully Convolutional Neural Networks for Volumetric Medical Image Segmentation



U-net (2015) and V-net (2016)

U-Net: Convolutional Networks for Biomedical Image Segmentation

Olaf Ronneberger, Philipp Fischer, and Thomas Brox



V-Net: Fully Convolutional Neural Networks for Volumetric Medical Image Segmentation

Fausto Milletari[1], Nassir Navab[1,2], Seyed-Ahmad Ahmadi[3]

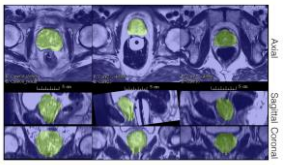
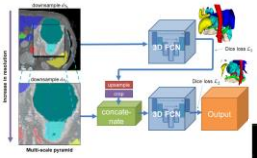
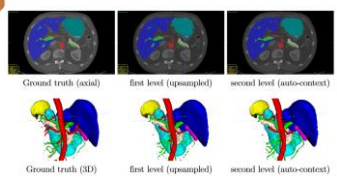
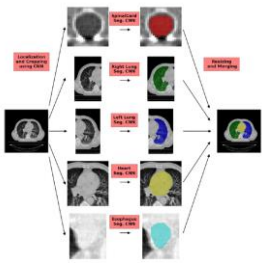


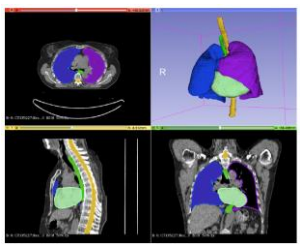
Fig. 4. Qualitative results on the PROMISE 2012 dataset [7].



Roth arXiv 2018







Feng MED PHYS 2019

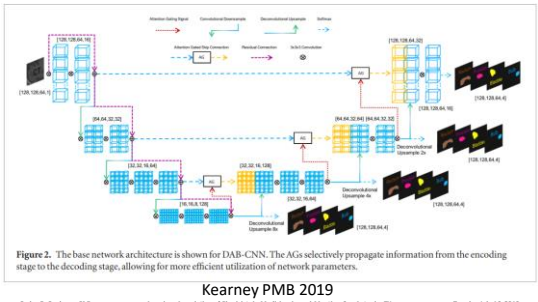
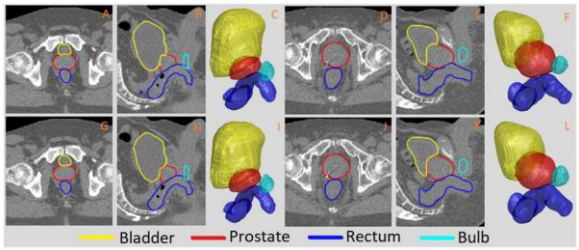
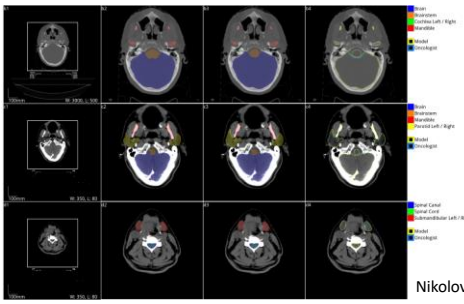


Figure 2. The base network architecture is shown for DAB-CNN. The AGs selectively propagate information from the encoding stage to the decoding stage, allowing for more efficient utilization of network parameters.

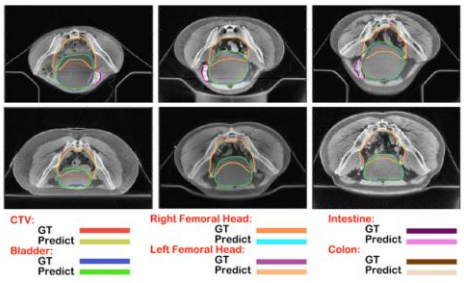
Kearney PMB 2019



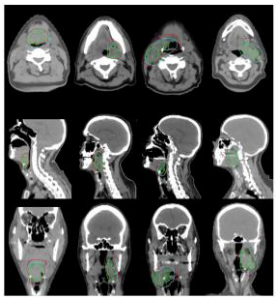
Kearney PMB 2019

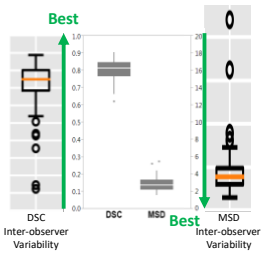


Nikolov arXiv 2018



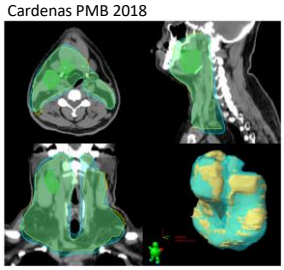
Men MED PHYS 2017

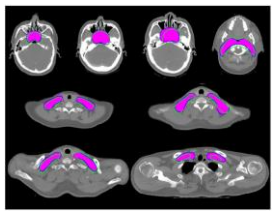




Cardenas IJROBP 2018

Cardenas PMB 2018





Men FRONT. ONC. 2017

Automation in Treatment Planning


Journal of Global Oncology
An American Society of Clinical Oncology Journal
Fully Automatic Treatment Planning for External-Beam Radiation Therapy of Locally Advanced Cervical Cancer: A Tool for Low-Resource Clinics


Predicting dose-volume histograms for organs-at-risk in IMRT planning


CLINICAL INVESTIGATION Physics
RAPID AUTOMATED TREATMENT PLANNING PROCESS TO SELECT BREAST CANCER PATIENTS FOR ACTIVE BREATHING CONTROL TO ACHIEVE CARDIAC DOSE REDUCTION

Physics Contribution
Fully Automated Volumetric Modulated Arc Therapy Plan Generation for Prostate Cancer Patients

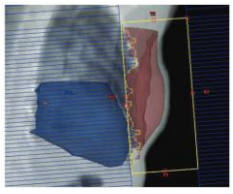
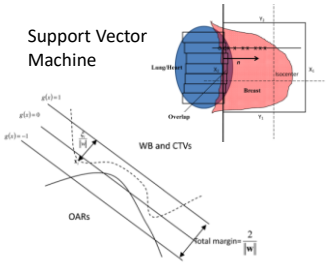
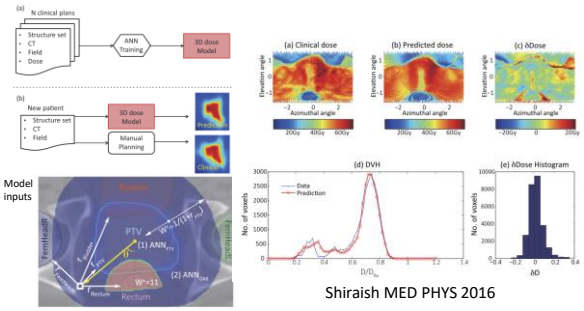


Fig. 5. Treatment field with blocks. The MLCs are illustrated as the blue rectangles and the resulting blocks are in yellow curve.

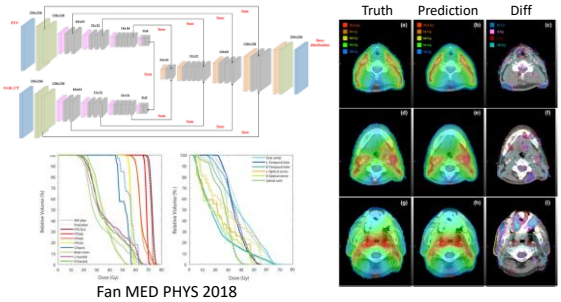
Zhao MED PHYS 2012

Support Vector Machine



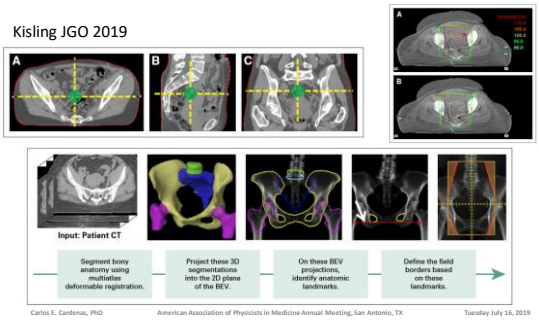


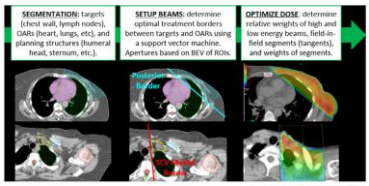
Shiraish MED PHYS 2016



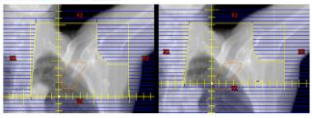
Fan MED PHYS 2018

Kisling JGO 2019



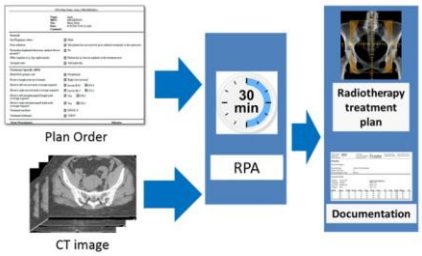


Kisling MED PHYS 2019

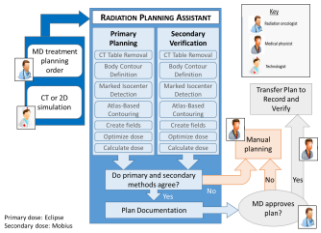


Radiation Planning Assistant

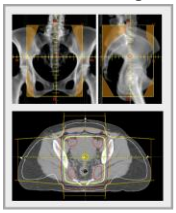
Court JOVE 2018



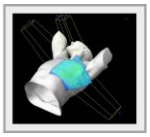
Radiation Planning Assistant



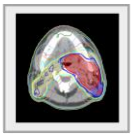
Radiation Planning Assistant



Cervix
Autodelineation of field arrangement
4-field box creation
Optimization of beam weights



Breast (chest wall)
Autocontouring normal tissues
Autocontouring target volumes
Determination of field arrangement
Dose optimization (field-in-field)



Head and Neck
Autocontouring normal tissues
Delineation of target volumes
VMAT plan creation

Coming Soon!

Thank you!

Contact Info
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MD Anderson Cancer Center
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